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The Reliability of Laser Reflowed Sn-Ag Solder Joints

C.H. Raeder, D.L. Millard, and R.W. Messler
Design and Manufacturing Institute, Rensselaer Polytechnic Institute, Troy, NY 12180

This is the second quarterly report of a project aimed at determining the reliability of electronic interconnects made with Sn-3.5wt%Ag solder alloy. Isothermal creep testing is now complete. The testing procedure is outlined in Report #1. Only results will be given here.

Each creep curve was decomposed assuming linear addition of three strain components: elastic, transient, and steady state strain. Young's modulus values of pure Sn as a function of temperature were taken from Drapkin and Kononenko [2]. These data were fit linearly resulting in the equation (1) given below which was used to calculate the elastic strain for a given test.

$$E = 55.7 - .0954 * T \tag{1}$$

Table 2.1: Modulus values used in data reduction.

Temperature	20	64	107	158
Modulus (MPa*10^{-3})	53.79	49.59	45.49	40.62

The calculated elastic strain was subtracted from the total strain/time data, leaving only the transient and steady state components of strain. The transient strain as a function of time for a given test was obtained by subtracting the steady state strain rate (the minimum strain rate observed) multiplied by time from the creep data. The transient strain reaches a limiting value (at steady state) which increases with applied stress at a given temperature.

Table 2.2 presents a summary of the creep testing. A total of 7 samples were used at four different temperatures. As more than one test was done with a given sample though at a single temperature, it was necessary to show that prior testing did not affect later observed strain rates. As such, a second sample, at a given temperature, was used to bound the high and low strain rates and a third to verify intermediate strain rate data.

Table 2.2. Steady State Creep Data, Sn-3.5wt%Ag

Specimen #	T(°C)	Stress (MPa)	Strain Rate (/sec)
1	20	16	3.52 E-7
		20	2.39 E-6
		25	1.12 E-5
		31	8.12 E-5
		40	7.52 E-4
2	64	10	1.51 E-6
		12	7.78 E-6
		14	2.48 E-5
		16	5.25 E-5
		26	1.86 E-3
3	107	7	3.82 E-6
		9	1.36 E-5
		12	1.62 E-4
		15.6	1.86 E-3
4	158	4	1.52 E-6
		5	8.05 E-6
		7	5.95 E-5
		11.2	1.53 E-3
5	20	12	2.85 E-8
	64	3.2	1.17 E-9
		5.4	2.28 E-8
		8	6.87 E-7
		32.2	7.92 E-3
6	107	3	5.33 E-9
		5	6.75 E-7
		23.5	3.03 E-2
7	158	2.5	9.60 E-8
		3	4.85 E-7
		16	1.00 E-2

Stress versus steady state strain rate is plotted for all test temperatures in Figure 2.1. The stress exponent, n, has two values. The tests at 20°C fit a line with n equal to 8.4, while the tests at higher temperatures each fit a line with n equal to 6.7. Using the high temperature value for the stress exponent (n=6.7) and equation (2), an Arrhenius plot of the data was constructed. This plot is seen in Figure 2.2. From this plot, the activation energy, Q, was

calculated and found to be 0.65 eV. Given n and Q the steady state creep data were fit with a power law constitutive equation as follows:

$$\dot{\mathcal{E}}_{ss} = \frac{CE}{kT}\left(\frac{\sigma}{E}\right)^n \exp\left(\frac{-Q}{kT}\right) \tag{2}$$

The constant, C, was calculated as 4×10^{23} eV/(MPa•sec) and E is given by equation (1). These values provide the fit to the high temperature (>20°C) data seen in Figure 2.1.

Transient Strain

The total accumulated transient strain, ε_t, for each test is plotted vs. stress in Figure 2.3. The data in Figure 2.3 show that the maximum transient strain increases linearly with stress. Though there was significant scatter in the data, it was fit by the following equation:

$$\varepsilon_\tau = \frac{\sigma}{\sigma_o} \tag{3}$$

where σ_o is a constant equal to 1.33E5 (MPa) and σ is the applied stress.

The transient strain versus time curve for each test was fit with an exponential equation of the form:

$$\varepsilon(t) = \varepsilon_\tau\left(1 - \exp\left(-t/\tau\right)\right) \tag{4}$$

where τ is the time constant. The time constant represents the time it takes for the transient strain to reach approximately 2/3 of its maximum value. Alternatively, it shows how quickly the creep rate of the material reaches its steady state value. The values of τ, obtained from a best fit of the data, show that τ decreases approximately linearly with the steady state strain rate:

$$\tau = \frac{\beta}{\dot{\mathcal{E}}_{ss}} \tag{5}$$

The constant β equals 1.9E-4 for $\dot{\mathcal{E}}_{ss}$ given in units of (/sec).

Equations 3, 4, and 5 are combined to give a transient constitutive relation as follows:

$$\varepsilon(t) = \left(\frac{\sigma}{\sigma_o}\right)^p \left(1 - \exp\left(-\frac{\dot{\varepsilon}_{ss} t}{\beta}\right)\right) \tag{6}$$

Discussion

The creep rate of SnAg is compared to that of pure Sn with a grain size of approximately 2 mm [1] in Figure 2.4. The pure Sn samples were prepared from recrystallized and aged samples. The alloys show similar stress dependence, but the Sn-3.5Ag creeps at a significantly lower rate for a given stress and temperature. The body centered tetragonal crystal structure makes it difficult to determine the actual deformation mechanism as most theories of stress dependence apply to cubic systems, but dislocation creep is most likely dominant; diffusional creep would occur with a low value of n at a much lower rate.

References

1. F. A. Mohamed, et al., "Harper-Dorn Creep in Al, Pb, and Sn," Metallurgical Transactions, Vol. 4, 1973, pp. 935-940.

2. B. M. Drapkin and V. K. Kononenko, "Temperature Dependence of Young's Modulus of Pb-Sn, Pb-Bi, and Sn-Bi Alloy," Izvestiya Akademii Nauk SSSR. Metally, No. 2, 1987, pp. 162-165.

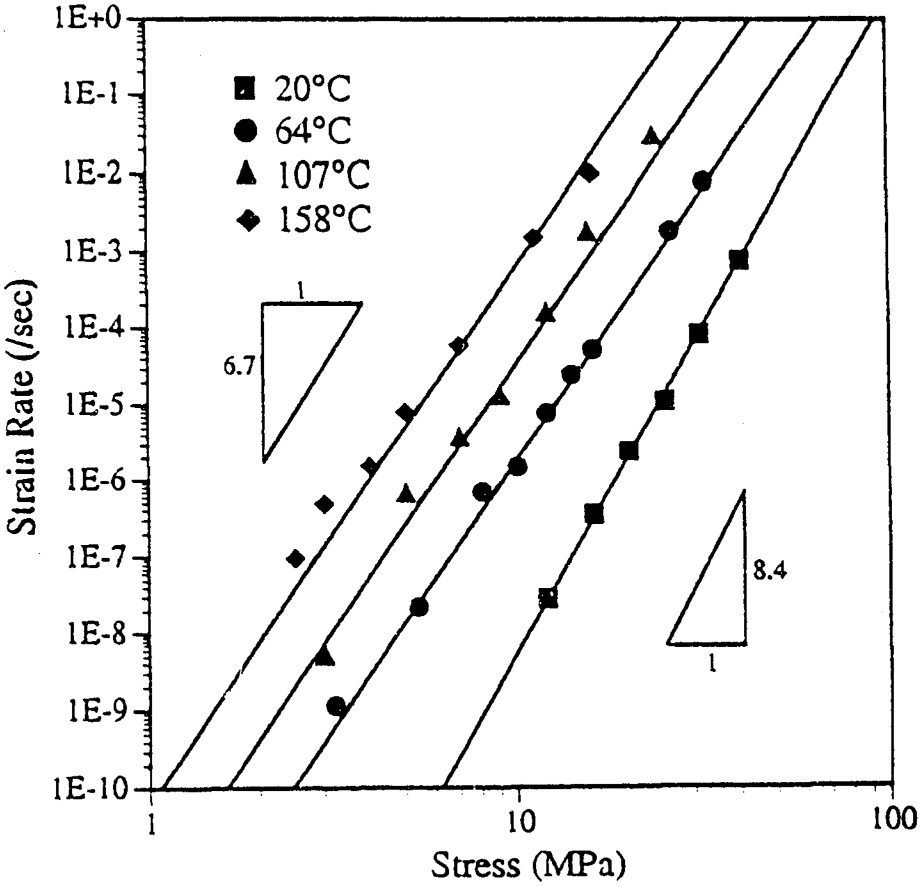

Figure 2.1. Steady State Creep of Sn-3.5wt%Ag

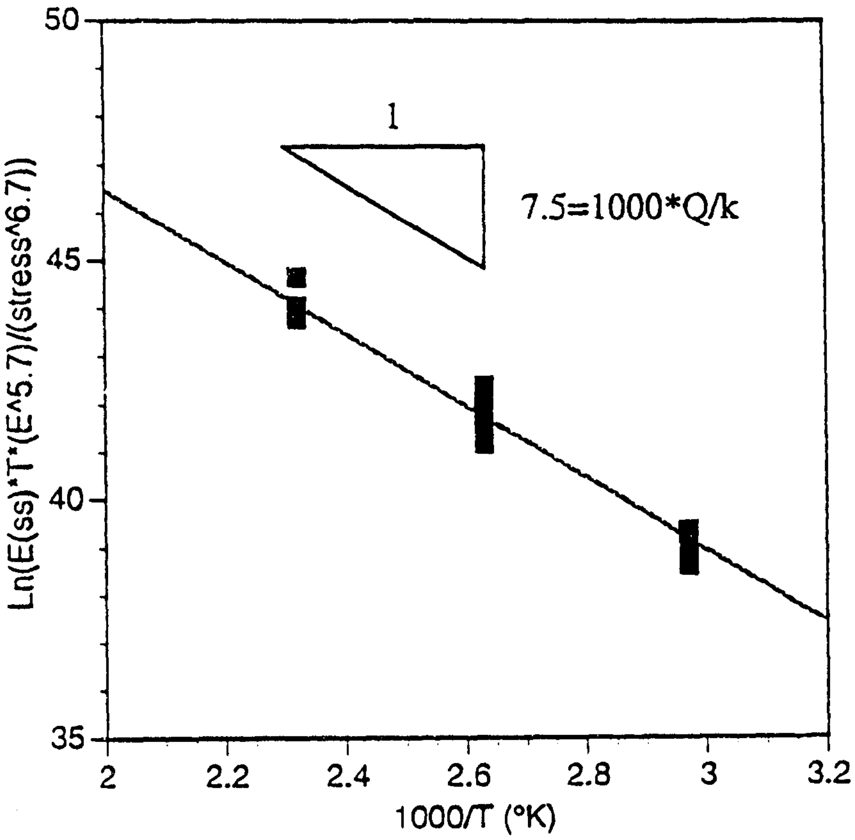

Figure 2.2. Arrhenius plot of Steady State Creep Data, Q = .65eV

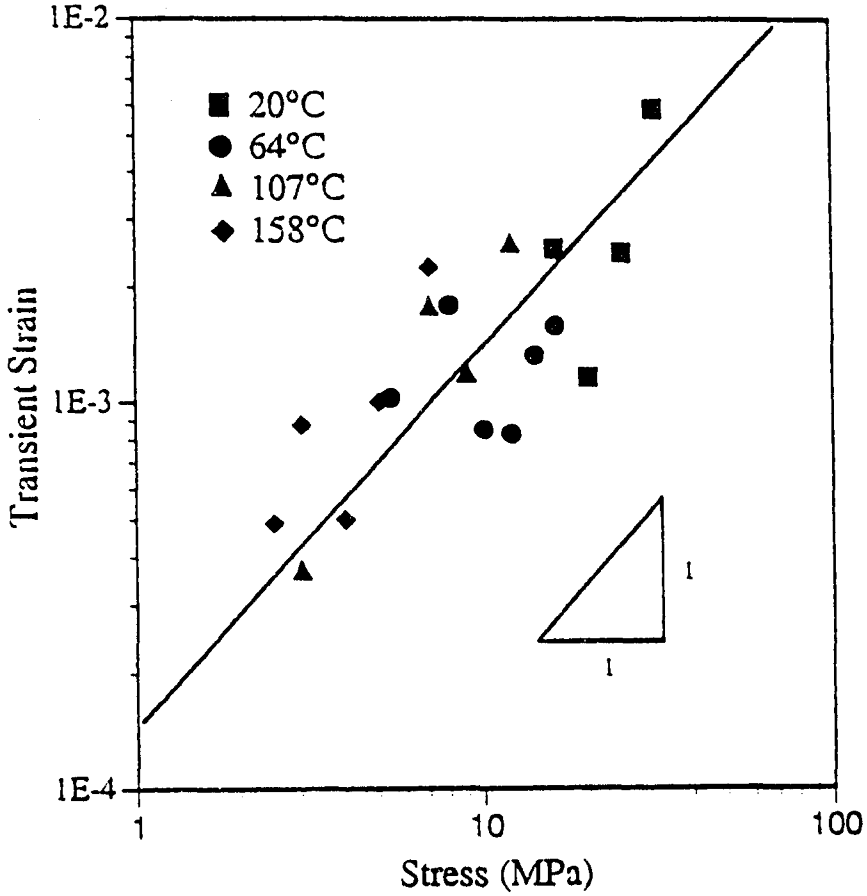

Figure 2.3. Transient strain vs. Stress, Sn3.5wt%Ag.

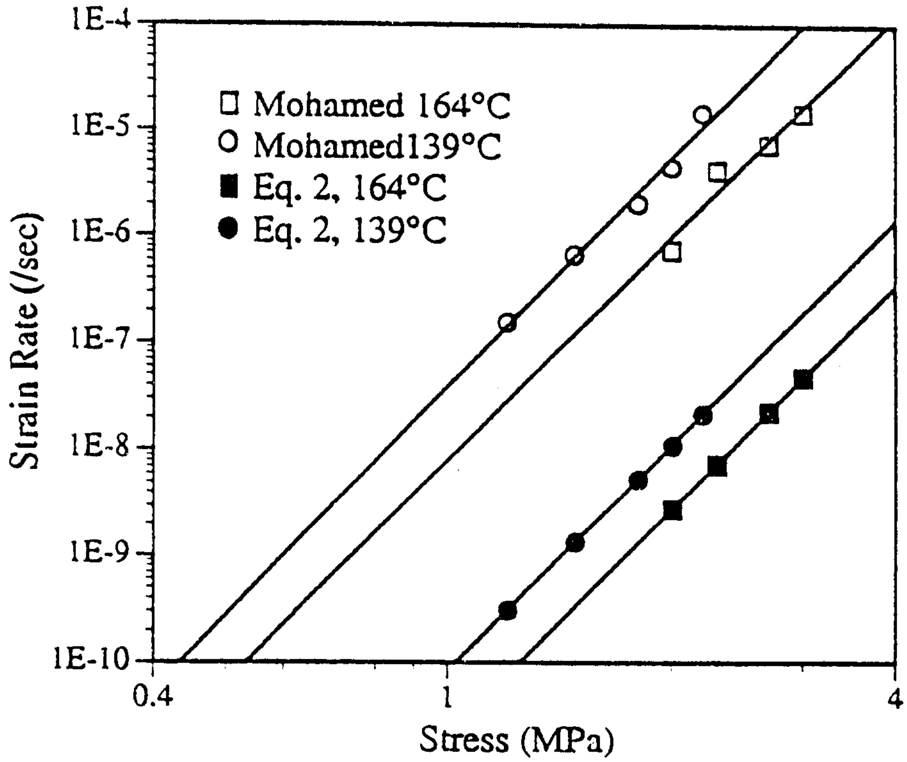

Figure 2.4. Comparison of Sn-3.5Ag steady state strain rate with pure tin data of Mohamed [1].